Alternative Penetrometers to Measure the Near Surface Strength of Soft Seafloor Soils

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LONG-TERM GOALS

Develop an alternative penetrometer to accurately measure the undrained shear strength of near surface soft seafloor soils. Further the education of participating undergraduate students by active involvement in research and mentoring activities.

OBJECTIVES

In collaboration with the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, assess the feasibility of using full-flow penetrometer technology to meet Navy requirements. Design, build, and test a full-flow penetrometer that will accurately measure the near surface shear strength of soft seafloor soils.

APPROACH

Review current full-flow penetrometer technology:
Review technical literature to evaluate the state-of-the-art in full-flow penetrometer technology. Discuss with end users and manufacturers the state-of-practice of full-flow penetrometers in scientific and engineering practice. Identify unresolved issues of flow-penetrometer technology and how they can be met to meet the needs of the Navy.

Probe design and construction:
Select probe type and size for design and construction. The probe will be designed to be compatible with the Navy's seabed cone penetrometer unit. The probe will be outfitted with load cells to measure penetration resistance, sleeve friction, and a pressure transducer to measure porewater pressures. Nearly all full-flow penetrometers in use today are either spherical (ball) or cylindrical (t-bar). The features and characteristics most critical to the needs of the Navy will dictate the selection of the probe type.

Laboratory Probe Calibration:
Calibration will be performed in the laboratory by pushing the full-flow penetrometer into prepared large-scale Kaolin specimens of known strength and comparing the measured resistance with the specimen's undrained shear strength. The ratio of these quantities is the experimentally determined

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laboratory probe factor. Adjacent cone penetrometer and vane shear tests will also be performed in the specimens to allow side-by-side comparisons and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. Also, undisturbed samples will be taken from the Kaolin specimens and tested by consolidated undrained triaxial compression/extension tests and by direct simple shear tests.

Probe Validation through Field Trials:
Field testing at onshore sites will be conducted to validate the recommended probe factors against real soils. The probe factors from the field trials will be calculated and compared with the theoretical and laboratory determined values. Ultimately, the potential of the full-flow penetrometer to more accurately determine the shear strength of soft soils (compared to the CPT and Vane Shear) will be evaluated. Parallel CPTs and vane shear tests will also be performed to allow side-by-side comparison and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. High quality undisturbed clay samples will be obtained for laboratory strength testing (triaxial and simple shear).

Educational Program:
One of the main objectives of this project is to actively involve undergraduate students in the research effort and to provide mentorship. The project involves three undergraduate civil engineering students in research and mentoring activities throughout the duration of the project.

WORK COMPLETED

The *Laboratory Probe Calibration* testing in the Kaolin specimens is complete. A total of five full-scale Kaolin specimens (Specimens 1 through 5) have been prepared and tested. Each specimen had final consolidated dimensions of approximately 1.1 m in diameter by 1.3 m in height. Each was prepared by mixing 2,700 pounds of Kaolin powder with 450 gallons of water and applying a consolidation pressure and allowing the water to drain at the top and bottom boundaries. Consolidating the specimens took about one to two months to complete depending upon the applied pressure. Turnaround time for each specimen was about 4 months. The equipment and procedures developed to prepare uniform and homogenous large-scale clay specimens has been a key accomplishment for this project.

The readied specimens were tested by advancing a standard ball penetrometer (100 cm^2), mini-ball penetrometer (20 cm^2), cone penetrometer (10 cm^2), and vane shear device. A photograph of the probes is shown on Figure 1. The results were used to evaluate and compare the undrained shear strengths derived from each device. Core samples were retrieved for subsequent triaxial and direct simple shear testing. Digital imaging was used to observe the flow mechanism during shallow penetration. A photograph showing the soil flow mechanism around the ball penetrometers after extraction is shown on Figure 2.

The *Probe Validation through Field Trials* phase is about half-way complete. The first field site was tested in August at a rock quarry site in Irwindale. Soft and fine grained tailings were tested in an old spreading pond at the site. A total of six spherical ball and cone penetrometer tests were performed over a two day period. Core samples were also retrieved. A photograph of the test site is shown on Figure 3. A second site for another round of testing is being located.

The *Education Program* component is ongoing and progressing well. Three undergraduate civil engineering students are working on the project; however, since January one of the students has dropped out of school due to personal reasons. The two remaining students are now seniors and are on track to graduate this year. Two graduate civil engineering students are also working on the project. One of the students completed his Master's thesis using the research results from the project and graduated in June. The other student participated in CSULA's research symposium, which showcases graduate student research activities on campus. He was presented with an Outstanding Presentation Award, which means the research was judged as one of the best on campus and he was selected as a delegate to participate in the CSU statewide competition that was held in May. He was able to showcase ONR's work in front of hundreds of other delegates from the CSU's 23 campuses. He will graduate in the Winter.

RESULTS

As mentioned earlier, five tests (Specimens 1 through 5) have been completed. Each test represents a different clay consistency. For each test, four different types of probes were advanced side-by-side in order to allow a comparison of the recorded data. The probes used were a cone penetrometer (CPT), standard ball penetrometer (BPT), mini-ball penetrometer (mBPT) and a shear vane (VST). The CPT and BPT measure electronically a continuous profile of tip and sleeve resistance as well as the porewater pressure during advancement. The mBPT measures a continuous profile of tip resistance. The VST records the undrained shear strength of the soil at discreet depths. In addition, Shelby tube samples were collected for triaxial and direct simple shear testing.

The average net tip resistance profiles for the CPT, BPT, and mBPT for Specimens 1 through 5 are shown on Figure 4. The shape and magnitudes of the tip resistance profiles are consistent and in line with other soft clay tests reported in the literature. As expected, the magnitudes of tip resistance increase as the soil becomes stiffer for each probe type. Comparing the tip resistances of all three probes in each soil shows that the CPT always shows the highest resistance followed by the mBPT and then the BPT. This is supported by other data in the literature and has been attributed to differences in soil flow mechanism between the cone and ball and possible scale effects. However, it is not yet fully understood why the mBPT resistances lie between the CPT and BPT. This phenomenon is being studied in more detail and potentially may affect the optimum size of ball penetrometer to select.

The undrained shear strengths computed using the cone and ball are currently being evaluated against the benchmark strengths from the VST and triaxial/simple shear tests. Thus far, the VST strengths have compared favorably with the results. Results from the triaxial and simple shear tests are ongoing. New to the work this year is the testing of core samples not only in triaxial compression but in *extension* as well. Determining strengths in compression and extension provides a more accurate baseline from which the probe results can be evaluated. Having the equipment to test specimens in these complex modes of failure is significant to our research lab capabilities.

Test results conducted at the quarry site in Irwindale are currently being evaluated. Resistance and strengths will be analyzed and presented in next year's report.

IMPACT/APPLICATIONS

The impact of the research is to increase the technical capabilities of the Navy by developing a tool to measure the strength of soft seafloor soils. Results of this research will provide immediate and

practical information for use by Navy commands. The project will also further the education of undergraduate and graduate students by active involvement in research and mentoring activities. It will expose the students to research projects important to the mission of the Navy with the intent that they may consider naval careers

RELATED PROJECTS

None

HONORS/AWARDS/PRIZES

Joe Beaty, a graduate student on the project, was presented with an Outstanding Oral Presentation Award at the CSULA Student Symposium on Research, Scholarship, and Creative Activity, February 25, 2011. He was also selected as a delegate to participate in the CSU Statewide Student Research Competition that was held on May 6, 2011.

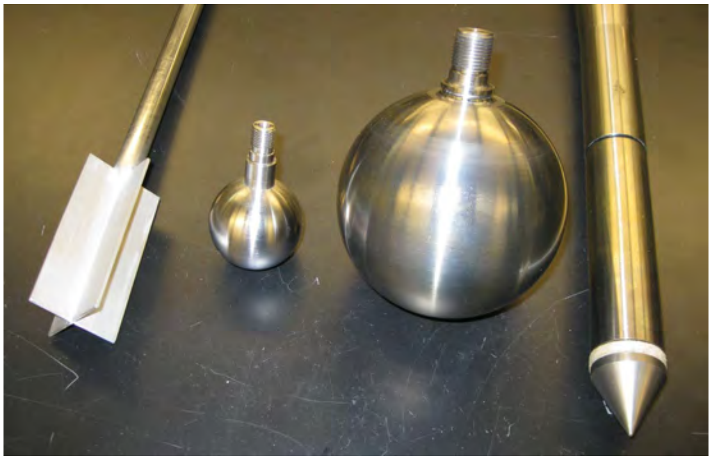

Figure 1: Photograph of probe types used in study. From left to right: vane shear, mini-ball, standard ball, and cone penetrometer.

Figure 2: Photograph of soil flow mechanism around mini-ball and standard ball penetrometers after extraction from laboratory clay specimen.

Figure 3: Photograph during preparation of ball penetrometer for testing in soft mine tailings at quarry site in Irwindale, California.

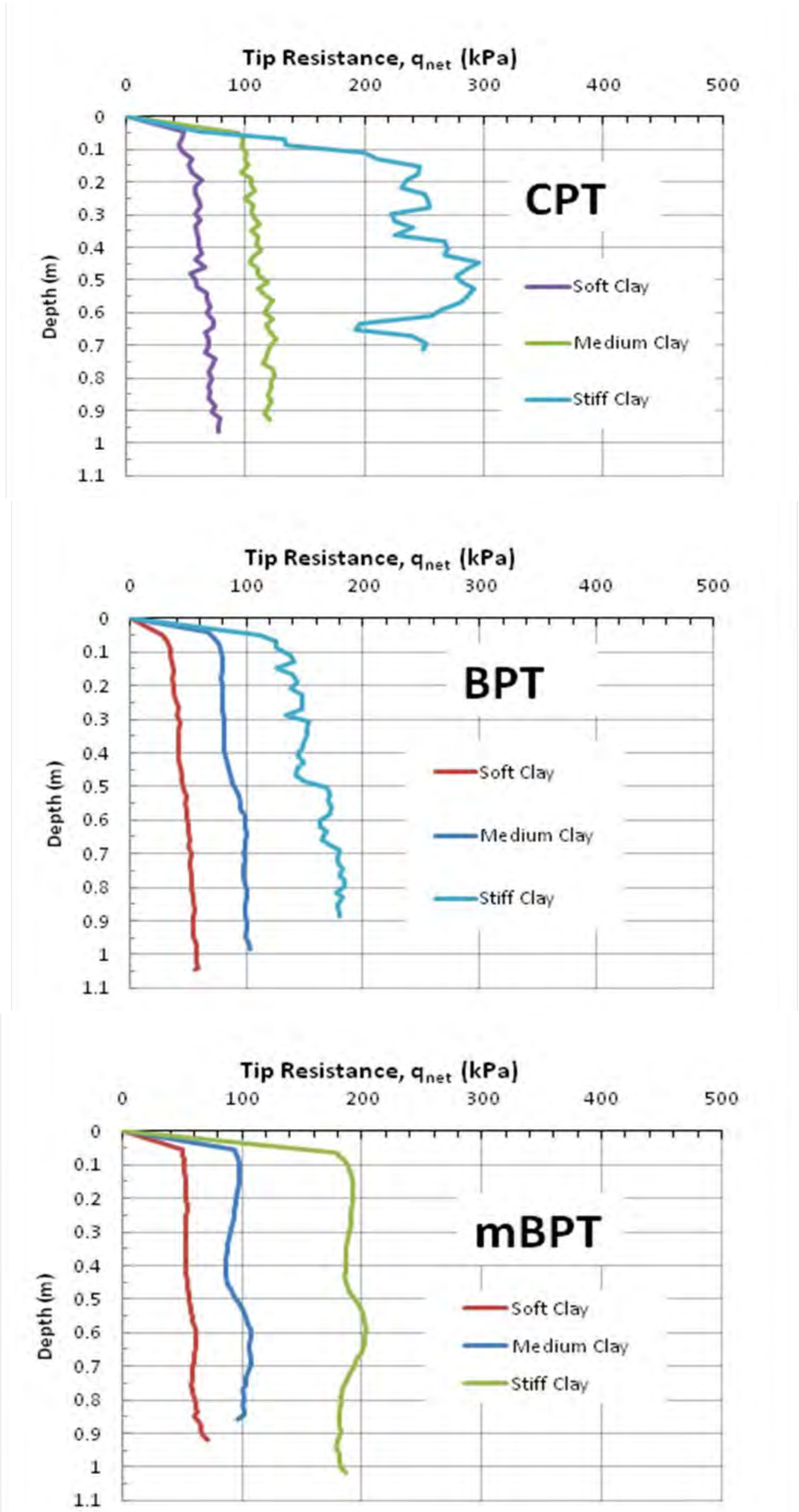

Figure 4: Graphs showing profile of average tip resistance with depth for the cone (CPT), ball (BPT) and mini-ball (mBPT) penetrometers in soft, medium, and stiff clay.